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A Conceptual Design of an Agent-based Interaction Model for the Carpooling Application

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Abstract

Carpooling is an emerging alternative transportation mode that is eco-friendly and sustainable as it enables commuters to save time, travel resource, reduce emission and traffic congestion. The procedure of carpooling consists of a number of steps namely (i) create a motive to carpool, (ii) communicate this motive with other interested agents, (iii) negotiate a plan with the interested agents, (iv) execute the agreed plans and (v) provide a feedback to all concerned agents. The state-of-the-art research work on agent-based modeling is limited to a number of technical and empirical studies that are unable to handle the complex agent behavior in terms of coordination, communication and negotiations. In this paper we present a conceptual design of an agent-based model (ABM) for the carpooling application that serves as a proof of concept. Our agent-based model for the carpooling application is a computational model that is used for simulating the interactions of autonomous agents and to analyze the effects of change in factors related to the infrastructure, behavior and cost. In our agent-based carpooling application we use *agent profiles* and *social networks* to initiate our agent communication model and then employ a route matching algorithm and a utility function to trigger the negotiation process between agents. We plan to, as a part of the future work, develop a prototype of our agent-based carpooling application on the basis of the work presented in this paper. Furthermore, we also intend to carry out a validation study of our results with real data.

Keywords: Agent-based model, Interaction, AgentProfile, Social network, Route matching algorithm, Utility function, FEATHERS.

1. Introduction

Nowadays carpooling is emerging transportation mode that is eco-friendly and sustainable as it enables commuters not only saves the travel cost, such as fuel, toll and parking costs, of the carpooling

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participants but also reduce emissions and traffic congestions. Carpooling, also known as ride-sharing, is the sharing of a car between a number of people(agents) from a certain origin to a certain destination. Thus, in order to study the carpooling concept we should take into account the interactions of two or more agents throughout the carpooling process.

The procedure of carpooling consists of a number of steps namely (i) create a motive to carpool, (ii) communicate this motive with other interested agents, (iii) negotiate a plan with the interested agents, (iv) execute the agreed plans and (v) provide a feedback to all concerned agents. Creating a motive means that a traveler (agent) may choose to carpool because of the availability of travel resources, time, monetary and route cost constraints.

Moreover, change in some socio-economic factors such as increase in fuel price or establishment of a new traffic policy, may trigger the initiative to carpool. Once to the decision has been made to carpool, the traveler (agent) will try to find one or more potential partners (agents). The carpool initiating agent will send a request to other interested agents in its vicinity. If one or more agents who receive this request are willing to carpool then they begin the negotiation phase. In this phase these agents will negotiate about sharing their travel resources and optimizing total costs and daily schedules. After reaching a compromise these agents can carpool. Meanwhile, an agent can appraise its partners according their degree of faithfulness to the carpooling. We call this degree of faithfulness as *AgentsReputation*. This reputation factor can serve as a criterion for the selection of a potential partner for carpooling.

An agent-based model (ABM) is a class of computational models for simulating the actions and interactions of autonomous agents with a view to assessing their effects on the systems as a whole [1]. ABM is now widely used for modeling increasingly complex systems [2]. Application of ABM is not only limited to the computer science domain. Currently many research areas such as transportation behavior modeling, need to analyze and model complex phenomenon of interactions between different entities. While traditional modeling tools cannot catch the complexity, ABM is able to do it through modeling the interaction of autonomous agents and deducing the rules for such a system. We, therefore, in this paper purpose an agent-based interaction model for the carpooling application.

This paper describes a conceptual design of the carpooling application using an agent-based model and mainly focuses on how agents interact with each other in terms of communication, coordination and negotiation. We present some related work on the carpooling concept and ABM in section 2. In section 3 and 4, we explain our ABM for the carpooling application with details about role of the agents and the environment. We conclude our paper with our concluding thoughts and ideas for future work in section 5.

2. Related Work

Related research about the carpooling concept is largely separated into two parts; (i) a technical study and (ii) an empirical study. The first part focuses on the development of carpooling support systems with travel route matching techniques [3,4]. In the second part the overall trend of carpooling or interrelationship between willingness-to-carpool and socio-economic attribute of carpooler in study area is treated as a topic in general [5,6]. The studies mentioned previously are limited and do not consider the potential agent (participants) interaction to perform carpooling.

Most transportation related applications of ABM are related to vehicle routing, pedestrian flow simulation or demand modeling efforts [7]. Among these applications two of the more widely known are TRANSIMS and MATSIM ABM simulation platforms. TRANSIMS, developed by Los Alamos Lab, is designed to supply transportation planners with more delicate information about traffic impacts, energy consumption, land use planning and emergency evacuation [8]. MATSIM is also a large-scale agent-based simulator similar to TRANSIMS, but it is different to use XML and to quickly run simulation because of more simplified traffic flow simulator [9]. Those applications only consider the whole effect of each agent's action in a system and cannot handle a detailed agent-to-agent or agent-to-environment coordination, communication and negotiation.

3. Agent-based Modeling (ABM)

Agent-based Modeling (ABM) is a computation model to simulate the actions and interactions of autonomous agents. In order to develop such a model, we need to define an agent and its environment where these agents will interact with each other. In this section, we provide with a basic definition of our agent and a set of activity rules with respect to the carpooling application.

3.1. What is an agent?

In this study, *agent* is defined as someone who lives in our study area and executes his or her own daily *schedule* in order to satisfy his or her needs. A *schedule* is a combination of a number of trips associated with a number of activities There are two categories of agents. An agent could either belong to one or both of the categories. The first category is a member of household such as the husband, the wife, the parents or the children. The second one is a member of the society such as a friend, a colleague, a neighbor, an employee (or an employer) or a student. In our model, we consider the socio-economic attributes including age, gender, income, education, relationship (within a family), job, vehicle and driving license ownership, as a set of input data. These schedule and attributes are supplied by FEATHERS [10], an activity-based traffic demand model, which is developed by the Transportation Research Institute (IMOB) at the Hasselt University in Belgium. The environment is established as the spatio-temporal aggregate where an agent lives and executes its own daily schedule. This aggregate is composed of residence, activity place (e.g. workplace, school and shopping mall) and transportation network (e.g. road, train, station) information.

3.2. Activity rules for agents

During a simulation run, agents follow a number of steps including; (i) goal setting, (ii) scheduling based on a given resource and environment (both are actually decided by the FEATHERS) and (iii) in the end, execution of the schedule. For example in case of the carpooling application, the agents involved intend to share a vehicle with a goal to reduce travel time or monetary cost according to the given transportation environment such as travel resource and network condition.

Environment may also affect the agents in a number of ways. For example, travel time may fluctuate by network condition, travel route can be shifted by construction of new transport facility or cost may change by establishment of a new policy. Agents respond to these effects by changing activity time or place or by choosing a new mode of transport or even consider rescheduling and rerouting. Besides these features mentioned earlier, agents also communicate with each other in order to sense, manipulate and adapt to any change in the environment. There are mainly three types of communication performed between agents; (i) inquire or inform to exchange or confirm information, (ii) cooperation to share a resource and (iii) competition for a (limited) resource. We have applied this cooperation among agents in our carpooling model. In our model for communication, agents exchange information about trip schedule through message passing. Moreover, we propose to use context-aware communication in order to avoid infinite loops in the propagation of the carpooling messages. We use social networks to select one or more possible agents to interact with each other for a certain duration. We will discuss this later in the paper.

Furthermore in detail, each agent periodically sends its interests to other representatives with similar social or other interests defined in their agent (social) profile (initially sent to all) agents in the neighborhood. Details about an A*gentProfile* will be discussed later in this paper. We piggy-back the interests of an agent on the same message. When a message (e.g. carpool request) arrives at one of the agents, the system tries to find a match. If there is a match, the agent is added as a potential candidate for carpooling. If not, the message will just be forwarded to the other agents in the neighborhood to continue the propagation of the message. We can keep the interests of an agent as one and zero values in a binary representation of a number (bit array). For example, if we consider the first three places of a binary number to show interest in carpooling, traffic and accident information, then "101" shows interest in carpooling and accident information and no interest in traffic information. We can find a match using a simple "logical and" operation.

4. Agent Interaction for the Carpooling Application

In this section, we will first present the communication and coordination aspects of an agent-based interaction model for the carpooling application. Later in this section, we will discuss the use of social networks for agent-based models and the negotiation procedure for agents interaction.

4.1. Communication and coordination

AgentProfile could be XML based containing information such as name, gender, household information, socio-economic factors, etc. This profile could also contain information about the feedback based score of other agents. SPARQL could be used for implementing such a behavior. The RDF query language SPARQL is used to allow efficient queries over the distributed knowledge. Each agent has a basic set of communication characteristics in the start of its interaction with other agents such as common interests (e.g. carpooling) and requirements (e.g. travel costs, travel time, travel route, car capacity or reputation).

$$CarpoolPotential(CP_n) = \{Location(L), SpatialRelevant(SR), Interests(I), Requirements(R)\} \qquad (1)$$

There should be a match between *CP* of all interacting agents (*An*). *SpatialRelevance* (*SR*) is the match between the origin and the destination of all interacting agents. In order to evaluate whether or not agents match, as shown in the Fig. 1, the distances between the respective origin and destination locations are used.

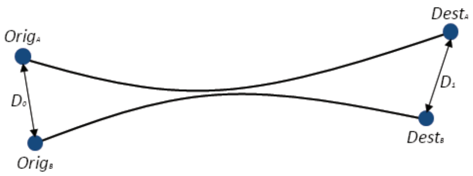

Fig. 1. Representing of the *SpatialRelevance* (SR) factor.

Reputation or *AgentReputation (AR)* is the reputation of an agent for being a potential carpooling candidate. It will help to perform Outlier Detection and ease out the decision making process. The reputation value is between 0 & 1 and is either increased or decreased based on the quality of its carpool (*QoC*) feedback (also between 0 & 1). In order to take into account the active participation of an agent in terms of the carpooling experience, we define Participation Factor pf as shown in the equation. In this formula i is number of former interactions between two or more agents for carpooling. We use a logarithmic function to map *i* to a value between 0 and 1. Moreover, the logarithmic function makes a gradual increase from 0 to 1. The Participation Factor is directly proportional to the change in *AR*. In this equation, T is the Reputation Threshold.

$$pf = 1 - \frac{log_2(i)+1}{i}, AR(n)_i = AR(n)_{i-1} + (QoC(m) - T) \times \frac{AR(n)_{i-1} \times pf}{SRDist} \quad (2)$$

Messages with a QoC feedback value greater than T increase AR and vice versa. SRDist is related to the SR factor that help reduce the negative effects of feedback from far agents.

4.2. Social Networks

A social structure made up of individuals (or organizations) called "links", which are tied (connected) by one or more specific types of interdependency, such as friendship, kinship, common interest, financial exchange, dislike, sexual relationships, or relationships of beliefs, knowledge or prestige.

We assume that if an agent has either any similar features, such as job, age and education, or the location of residence or work (or school) with another, then they seem to have any relationship with each other. In this study, we only consider two-way relationship in society, because one-way one is more complex to build and model a social network. The strength of relationship can be measured by calculating the number of similar attributes and the similarity of attribute for the agents.

We can infer potential carpooling participants (agents) among the population according to their socio-demographic attributes because social relationship could trigger for someone to carpool with someone who is related, such as a friend, colleague and so on. Formerly unrelated agents can become related because of having similar timing, origin and destination for their intended trips. Related agents first decide whether to carpool and if so, they negotiate an optimal route. Strong relationship makes carpooling continue for a relatively long period because it can give a guarantee of more reliability and safety. Therefore, the social network of agents enables the model to select a potential carpooling partner with an willingness-to-carpool and (his or her) possible-potential partner among the whole population. Laplacian matrix can be applied to construct social network for carpooling. In the mathematical field of graph theory the Laplacian matrix, sometimes called admittance matrix or Kirchhoff matrix, is a matrix representation of a graph. Given a graph G with n vertices, its Laplacian matrix $L := (\ell_{i,j})_{n \times n}$ is defined as (see Equation 3):

$$\ell_{i,j} := \begin{cases} 1 & if\, i = j \\ ST_{i,j} \times CL_{i,j} & if\, i \neq j \text{ and } v_i \text{ is adjacent to } v_j \\ 0 & otherwise \end{cases} \quad (0 \leq \ell_{i,j} \leq 1) \quad (3)$$

$ST_{i,j}$: Strength of relationship between agent i and j, $CL_{i,j}$: Closeness of relationship

4.3. Negotiation

Negotiation is an important step in an agent-based model (ABM). About the negotiation phase in an ABM we need to answer the following three questions;(i) What are the issues over which negotiation takes place?, (ii) What negotiation protocols will be used? And (iii) What reasoning model will the agents employ?

First of all, we considered trip route and time as issues for carpooling. A whole route matched consist of two terminal nodes (origin and destination), nodes (transit point), and segments (shortest path between two nodes, either a terminal node or an internal node). In the route, X, X' and X'' illustrate origin, transit and destination, respectively. For example, for agent *A*, $a, a'$and a'' means agent *A*'s origin, transit and destination location. In order to match the two routes for agent *A* and *B*, we can follow below procedure in order (see Fig. 2.):

I. Matching point features (terminal node and node)
  1) Finding the nearest neighbour to each point using range search

2) Calculating a gap between each pairs for two nearest points
3) Drawing a related network according to whether the gap is bounded by a walking distance

II. Matching linear features (segment)
1) Finding the shortest path
2) Making possible routes for carpooling

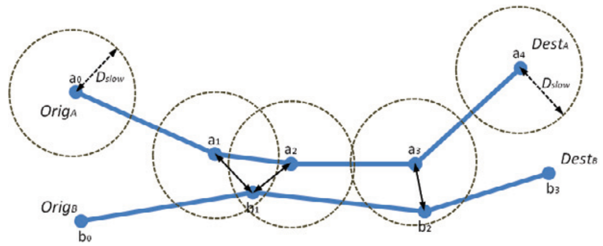

Fig. 2. Route matching for the carpooling application.

On the one hand, reduced travel time is important for the carpooling participants (agents) i.e. the driver and the rider but generally this factor is critical for the rider due to its goal of time saving. On the other hand, a driver intends to save the travelling cost, rather than time. In this study, we use the term time window to model both matching a trip schedule and a negotiation mechanism for carpooling. Time window consists of three factors of time which are earliest and latest departure time at the origin and latest arrival time at the destination, t^d_e, t^d_l and t^a_l. Furthermore, Δt^d is called temporal flexibility, which is used as a negotiation factor, as well as a spatial flexibility, Δd^{ij}(walking available distance).

In the model, agents negotiate to agree on a deal. Each agent is assumed to have a preference over all possible deals. They want to maximize their own utility but they also face the risk of a break-down in negotiation, or expiration of a deadline for agreement. Therefore, we regard negotiation for carpooling as the bargaining problem, which is a problem of understanding how two agents should cooperate when non-cooperation leads to Pareto-inefficient results. In the bargaining problem, each agent i has a utility function u_i defined over the set of all possible deals Δ. That is, $u_i : \Delta \rightarrow \Re$. We also assume that there is a special deal δ^- which is the no-deal. Without loss of generality we will assume that for all agents $u_i(\delta^-) = 0$ so that the agents will prefer no deal than accepting any deal with negative utility [11].

Let $c_i(\delta^-)$ and $c_i(\delta)$ be the cost of the agent i with a no-deal (δ^-) and a deal (δ), respectively. When the deal (δ) is selected, the utility function is defined as:

$$u(\delta) = \Delta c(\delta) = c(\delta^-) - c(\delta) \qquad (4)$$

Thus, both agent i and j seek to maximize the utility u(δ), that is, to minimize $c(\delta)$. Because the total cost for carpooling with the deal n comes to agent i's cost $c_i(\delta)$ and agent j's cost $c_j(\delta)$, the most reasonable solution is to divide the profit as shown the equation.

$$c_i(\delta) \Rightarrow c_i(\delta) + \frac{\Delta c_i(\delta)+\Delta c_j(\delta)}{2}, \qquad c_j(\delta) \Rightarrow c_j(\delta) + \frac{\Delta c_i(\delta)+\Delta c_j(\delta)}{2} \qquad (5)$$

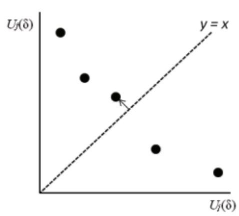

Fig. 3. Carpooling utility function.

Therefore, as shown in the Fig. 3, we can choose the closest deal to $y = x$ graph among the possible deals.

5. Discussion and Future Work

In comparison to the state-of-the-art research work, the work / study presented in this paper has a number of advantages. Some of these advantages include; (i) the ability to analyze various effects of agent interaction with a detailed view on both communication and negotiation aspects, (ii) the ability to simulate learning, adaptation and features reproduction of agents through modeling their interactions. In spite of the advantages, our agent-based interaction model also has few drawbacks such as; (i)the need of not only a huge computing resource (e.g. memory and data storage) because of the big data processing for each agent and (ii) detailed and accurate input data requirement including agent's socio-economic attributes, network information and so on. At this moment, this study is to conceptually design an agent-based interaction model for the carpooling application. As a part of the future work, we intend to develop a prototype for carpooling application based on our conceptual design presented in this paper. We also plan to test our prototype with a small sample realistic data and do the validation of our outcome.

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